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TI Free-cutting steels for bearing elements with long rolling-contact fatigue life
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AB The steels comprise **C** 0.8-1.2, **Si** 0.2-2.0, **Mn** 0.2-1.5, **Cr** 0.6-2.0, Al ≤0.05, **Cu** ≤2.0, **Ni** ≤4.0, **Mo** ≤0.5, V ≤0.2, Nb ≤0.10, Ca ≤0.003, Mg ≤0.003%, and balance **Fe** and satisfy 5.0 ≤ 1.6[**Si**] + 4.0[**Mn**] + 3.0[**Cr**] + 5.0[**Mo**] ≤ 9.0 and total concentration of **Cr** and **Mn** in cementites ≥5.0%. Inevitable impurities in the steels satisfy Ti ≤0.002, P ≤0.02, S ≤0.015, N ≤0.009, and O ≤0.0015%.

PATENT ABSTRACTS OF JAPAN

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(54) STEEL FOR BEARING ELEMENT PARTS HAVING EXCELLENT MACHINABILITY

(57)Abstract:

PROBLEM TO BE SOLVED: To provide steel (a steel wire rod, bar steel and a steel pipe) for bearing element parts which has excellent machinability and a rolling fatigue life.

SOLUTION: The steel has a composition containing 0.8 to 1.2% C, 0.2 to 2.0% Si, 0.2 to 1.5% Mn, 0.6 to 2.0% Cr, ≤0.05% Al, ≤2.0% Cu, ≤4.0% Ni, ≤0.5% Mo, ≤0.2% V, ≤0.10% Nb, ≤0.003% Ca and ≤0.003% Mg, and the balance Fe with impurities. As the impurities, ≤0.002% Ti, ≤0.02% P, ≤0.015% S, ≤0.009% N and ≤0.0015% O are controlled. The relation among Si, Mn, Cr and Mo satisfies the inequality of $5.0 \leq 1.6\times\%Si+4.0\times\%Mn+3.0\times\%Cr+5.0\times\%Mo \leq 9.0$, and the concentration of Cr+Mn in cementite is ≥5.0%.

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* NOTICES *

CLAIMS

[Claim(s)]
[Claim 1] By mass %, C:0.8 - 1.2%, Si:0.2-2.0%, Mn:0.2-1.5%, Cr: 0.6-2.0%, less than [aluminum:0.05%], less than [Cu:2.0%], nickel: Less than [4.0%], less than [Mo:0.5%], V:0.2% or less, less than [Nb:0.10%], Contain less than [calcium:0.003%] and less than [Mg:0.003%], and the remainder consists of Fe and an impurity. For 0.002% or less and P, 0.02% or less and S are [Ti in an impurity / 0.009% or less and O (oxygen) of 0.015% or less and N] 0.0015% or less. (1) of the following [relation / between Si, Mn, Cr, and Mo] Steel materials for bearing element components excellent in the machinability which fills a formula and is characterized by the sum density of Cr and Mn in a cementite being 5.0% or more.
5.0 <=1.6x%Si+4.0x%Mn+3.0x%Cr+5.0x%Mo<=9.0 ... (1)

[Translation done.]

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Field of the Invention] This invention relates to the steel materials for bearing element components excellent in the suitable machinability for the application of bearing element components, such as a ball which constitutes bearing, koro, a needle, a shaft, and a ball race.
[0002]
[Description of the Prior Art] Generally as material steel of bearing element components, such as a ball, koro, a needle, a shaft, and a ball race, it is JIS. G High-carbon-chromium bearing steel, such as SUJ2 steel specified to 4805, is used abundantly.
[0003] After the so-called above-mentioned "steel for bearing" is processed with means, such as hot rolling, it receives spheroidizing aiming at softening, subsequently cold forging, cold drawing, cutting, etc. are processed into it, and a desired mechanical property is further given to it in response to hardening and heat treatment by annealing at low temperature.
[0004] The demand to the steel for bearing with which cost was excellent in the machinability which becomes extensible [improvement in cutting speed or a tool life] since cutting increased is very large among each above-mentioned process.
[0005] In free-cutting elements (machinability improvement element), such as Pb and S, if it is made to compound and adds, it is well known by steel independent or that machinability will improve. However, high planar pressure acts on the bearing used for various kinds of industrial machines, automobiles, etc. repeatedly. For this reason, if said free-cutting element is added to the steel for bearing, the rolling fatigue life of bearing (element components) will fall sharply. Furthermore, generally said free-cutting element reduces hot-working nature. Therefore, there is also a problem of becoming easy to generate a surface check and a crack, at the time of hot working, such as hot rolling.
[0006] For this reason, the "excellent in machinability high Si-low Cr bearing steel" which made REM (rare earth elements) contain in steel is indicated by JP,1-255651,A. However, the yield of REM in the inside of steel is unstable in order to tend [very] to oxidize. Moreover, it is industrially difficult to control the particle size and the distributed condition of the REM oxide which is easy to generate in steel. If a big and rough REM oxide generates or a REM oxide generates so much, a rolling fatigue life will fall sharply.
[0007] "The bearing steel excellent in machinability" which raises machinability is indicated by JP,3-56641,A, without reducing a rolling fatigue life by making BN compound generate into steel. However, since the solubility to the inside of steel is small, the yield of B in the inside of steel is unstable, and it also tends to produce a segregation. Furthermore, since B reduces the coagulation initiation temperature of high-carbon steel remarkably, solidifying segregation will be conjointly promoted with the segregation of B. In addition, the fall of coagulation initiation temperature leads to the fall of hot-working nature, and it becomes easy to generate a surface check and a crack at the time of hot working. Therefore, it was not not necessarily being

stabilized on a scale of industrial as for 0.004 - 0.020%, and being able to manufacture bearing element components with the value to which B content of the steel for bearing was specified in said official report even if, i.e., mass %,, either.
[0008] "The bearing steel which is excellent in machinability and cold-working nature and its manufacture approach" of heat-treating in JP,9-227991,A on condition that specification, and adjusting the number of carbide and hardness under organization to it are indicated. However, it is necessary to perform gradual heating or isothermal maintenance in the middle of a heating process on the annealing conditions proposed in this official report. For this reason, annealing time amount becomes long and causes the fall of productivity. Furthermore, when being aimed at the rolling-up coil which is the general configuration of steel-wire material ("steel-wire material" is only hereafter called "wire rod") since heat treatment conditions need to be changed, such as gradual heating, rapid heating, and annealing, for example, it is difficult to heat-treat the whole coil to homogeneity (annealing processing). It will be difficult to carry out annealing on the conditions as which the continuation heat treating furnace used on a scale of industrial was specified in said official report since the temperature of each zone was generally decided and the number of zones was also restricted, even if it can perform uniform heat treatment, in order to anneal by the provision, a continuation heat treating furnace will need reconstruction and updating, and cost will increase.
[0009] According to the technique proposed in each above-mentioned official report, the steel materials and concrete target which were excellent in ******** once can get a wire rod, a steel bar, and a steel pipe. However, as already stated, there were productivity and a big problem in respect of quality.
[0010]
[Problem(s) to be Solved by the Invention] It is offering the steel materials (a wire rod, a steel bar, or steel pipe) excellent in the suitable machinability for the application of bearing element components, such as a ball, koro, a needle, a shaft, and a ball race, without causing the fall of productivity, without having made this invention in view of the above-mentioned present condition, and the purpose carrying out addition content of the free-cutting element specially, since annealing time amount is also the about 10 - 20 same hours as usual.
[0011] In addition, it is 1.0x107 by the rolling fatigue test in the below-mentioned example since high planar pressure acts on bearing repeatedly as already stated. It aims at having a rolling fatigue life more than a time.
[0012]
[Means for Solving the Problem] The summary of this invention is in the steel materials for bearing element components excellent in the following machinability.
[0013] By mass %, C:0.8 - 1.2%, Si:0.2-2.0%, Mn:0.2-1.5%, Cr: 0.6-2.0%, less than [aluminum:0.05%], less than [Cu:2.0%], nickel: Less than [4.0%], less than [Mo:0.5%], V:0.2% or less, less than [Nb:0.10%], Contain less than [calcium:0.003%] and less than [Mg:0.003%], and the remainder consists of Fe and an impurity. For 0.002% or less and P, 0.02% or less and S are [Ti in an impurity / 0.009% or less and O (oxygen) of 0.015% or less and N] 0.0015% or less. The steel materials for bearing element components excellent in the machinability which the relation between Si, Mn, Cr, and Mo fills a formula "5.0 <=1.6x% Si+4.0x%Mn+3.0x%Cr+5.0x%Mo<=9.0", and is characterized by the sum density of Cr and Mn in a cementite being 5.0% or more.
[0014] In above-mentioned this invention, about seven elements of Cu, nickel, Mo, V, Nb, calcium, and Mg, addition content may not necessarily be carried out among each above-mentioned element, and you may be the amount level of impurities. Moreover, the steel materials said to this invention mean a wire rod, a steel bar, or a steel pipe.
[0015] this invention persons repeated investigation and research about the effect the organization after spheroidizing of a wire rod, a steel bar, and a steel pipe, Cr in a cementite,

Mn concentration, and cementite particle size affect machinability, consequently acquired the following knowledge.
(a) In cutting of the steel for bearing, the hardness of the carbide in cut material influences a tool life and upper limit cutting speed greatly.
(b) If Cr and Mn condense in a cementite, it is known that a cementite will harden, but if Cr in the ferrite which is a matrix, and Mn decrease, the more it softens and the hardness difference of a cementite and the ferrite which is a matrix becomes large, the more machinability of a ferrite will improve.
(c) in order to raise Cr in a cementite, and Mn concentration, after metamorphosing into a ferrite from an austenite into spheroidizing -- annealing -- or what is necessary is just to carry out the retention
(d) What is necessary is for the hardenability more than fixed to need to be secured, in order to secure a rolling fatigue life, and just to control the content of Si, Mn, Cr, and Mo for that purpose.
[0016] This invention is completed based on the above-mentioned knowledge.
[0017]
[Embodiment of the Invention] Hereafter, this invention is explained in detail. In addition, "mass %" is meant"%" below.
(A) Although C:0.8 - 1.2% of chemical composition C performs hardening and heat treatment by annealing at low temperature and a desired mechanical property is made to give the steel materials for bearing (bearing element components), the content of the degree of hardness after hardening annealing is low at less than 0.8%, and a desired rolling fatigue life (it is a rolling fatigue test in the below-mentioned example, and is a rolling fatigue life more than a 1.0x107 time) is not acquired. On the other hand, if the content of C exceeds 1.2%, the coagulation initiation temperature of steel falls, and when steel materials are steel pipes especially at the time of hot working, a crack and cracks will occur frequently at the time of tube manufacturing between heat. Moreover, since it becomes easy to generate huge carbide at the time of the coagulation of steel, when not performing homogenization heat treatment of long duration, a target rolling fatigue life is not acquired. Therefore, C content was made into 0.8 - 1.2%. The desirable range is 0.8 - 1.0%, and the more desirable range is 0.8 - 0.9%.
[0018] Si: 0.2 - 2.0%Si is an element effective in raising a rolling fatigue life, and also is also an element required as a deoxidizer. Moreover, Si is also the element which raises the hardenability of steel. However, at less than 0.2%, the effectiveness of the above [the content] is difficult to get. In addition, if the content of Si becomes 0.6% or more, the improvement effectiveness in machinability will also become large. On the other hand, if the content of Si exceeds 2.0%, since long duration is required in order to carry out descaling after hot rolling and spheroidizing, the sharp fall of productivity will be caused. Therefore, Si content was made into 0.2 - 2.0%. The desirable range is 0.5 - 1.5%, and the more desirable range is 0.5 - 1.0%.
[0019] Mn: It is an element required for prevention of the hot shortness by S at the same time Mn raises the hardenability of steel 0.2 to 1.5%. In order to demonstrate such effectiveness, it is necessary to make Mn contain 0.2% or more. On the other hand, if the content of Mn exceeds 1.0%, the main segregation of not only Mn but C will come to arise, and if it exceeds 1.5%, the main segregation of Mn and C will become remarkable and will cause the fall of a rolling fatigue life. Therefore, Mn content was made into 0.2 - 1.5%. The desirable range is 0.2 - 1.0%, and the more desirable range is 0.2 - 0.8%.
[0020] Cr: 0.6-2.0%Cr is the element which is easy to condense in a cementite, stiffens a cementite and raises machinability at the same time it raises the hardenability of steel. However, at less than 0.6%, the effectiveness of the above [the content] is difficult to get. On the other hand, if it exceeds 1.6%, the main segregation of not only Cr but C element will come

to arise, and if it exceeds 2.0%, the main segregation of Cr and C will become remarkable and will cause the fall of a rolling fatigue life. Therefore, Cr content was made into 0.6 - 2.0%. The desirable range is 0.6 - 1.6%, and the more desirable range is 0.6 - 1.3%.
[0021] aluminum: Although aluminum is added as a deoxidizer 0.05% or less, superfluous aluminum forms nonmetal system inclusion and please give me a rolling fatigue life low. If the content exceeds 0.05% especially, big and rough nonmetal system inclusion will be formed, the remarkable fall of a rolling fatigue life will be caused, and a desired rolling fatigue life (by the rolling fatigue test in the below-mentioned example, it is a rolling fatigue life more than a 1.0x107 time) will no longer be acquired. Therefore, the content of aluminum was made into 0.05% or less. A desirable upper limit is 0.04% and a more desirable upper limit is 0.03%. On the other hand, in order to acquire sufficient deoxidation effectiveness, it is good to make the content into 0.0003% or more. In addition, when deoxidation is fully made by the above-mentioned Si, it is not necessary to necessarily add aluminum, and the content may be the amount level of impurities.
[0022] Cu: Less than [2.0%] (the desirable range at the time of addition is 0.05 - 2.0%)
It is not necessary to add Cu. If it adds, there is an operation which raises corrosion resistance. In order to acquire this effectiveness certainly, as for Cu, it is desirable to consider as 0.05% or more of content. However, if the content exceeds 2.0%, it will segregate to the grain boundary and the crack at the time of hot working, such as slabbing of a steel ingot and hot rolling of a wire rod, and generating of a crack will become remarkable. Therefore, the content of Cu was made into 2.0% or less. A desirable upper limit is 1.5% and a more desirable upper limit is 1.0%.
[0023] nickel: Less than [4.0%] (the desirable range at the time of addition is 0.2 - 4.0%)
It is not necessary to add nickel. If it adds, it has the operation which dissolves in the martensite after hardening and raises toughness. In order to acquire this effectiveness certainly, as for nickel, it is desirable to consider as 0.2% or more of content. However, even if it makes it contain exceeding 4.0%, the aforementioned effectiveness is saturated and cost just increases. Therefore, the content of nickel was made into 4.0% or less. A desirable upper limit is 3.0% and a more desirable upper limit is 2.0%.
[0024] Mo: Less than [0.5%] (the desirable range at the time of addition is 0.05 - 0.5%)
It is not necessary to also add Mo. If it adds, there is an operation which raises hardenability and raises a rolling fatigue life. In order to acquire this effectiveness certainly, as for Mo, it is desirable to consider as 0.05% or more of content. However, if the content exceeds 0.5%, hardenability will become high too much, and it will become easy to generate martensite after hot rolling, and will become easy to generate a crack. Therefore, the content of Mo was made into 0.5% or less. A desirable upper limit is 0.3% and a more desirable upper limit is 0.2%.
[0025] V:0.2% or less (the desirable range at the time of addition is 0.03 - 0.2%)
It is not necessary to add V. If it adds, austenite crystal grain is made to make it detailed, and it has the operation which raises toughness. In order to acquire this effectiveness certainly, as for V, it is desirable to consider as 0.03% or more of content. However, even if it makes it contain exceeding 0.2%, the aforementioned effectiveness is saturated and cost just increases. Therefore, the content of V was made into 0.2% or less. A desirable upper limit is 0.1%.
[0026] Nb: Less than [0.10%] (the desirable range at the time of addition is 0.01 - 0.10%)
It is not necessary to add Nb. If it adds, austenite crystal grain is made to make it detailed, and it has the operation which raises toughness. In order to acquire this effectiveness certainly, as for Nb, it is desirable to consider as 0.01% or more of content. However, even if it makes it contain exceeding 0.10%, the aforementioned effectiveness is saturated and cost just increases. Therefore, the content of Nb was made into 0.10% or less. A desirable upper limit is 0.08% and a more desirable upper limit is 0.05%.

[0027] calcium: It is not necessary to add calcium 0.003% or less. If it adds, it has the operation which raises hot-working nature. In order to acquire this effectiveness certainly, as for calcium, it is desirable to consider as 0.0001% or more of content. However, even if it makes calcium contain exceeding 0.003%, the aforementioned effectiveness is saturated and cost just increases. Therefore, the content of calcium was made into 0.003% or less. A desirable upper limit is 0.002%.
[0028] Mg: It is not necessary to also add Mg 0.003% or less. If it adds, it has the operation which raises hot-working nature. In order to acquire this effectiveness certainly, as for Mg, it is desirable to consider as 0.0001% or more of content. However, even if it makes Mg contain exceeding 0.003%, the aforementioned effectiveness is saturated and cost just increases. Therefore, the content of Mg was made into 0.003% or less. A desirable upper limit is 0.002%.
[0029] In this invention, it is important to restrict the content of Ti, P, S, N, and O (oxygen) as an impurity as follows. The reason is as follows.
[0030] Ti: 0.002%or less Ti will combine with N, will form TiN, and will reduce a rolling fatigue life. If especially the content exceeds 0.002%, the fall of a rolling fatigue life will become remarkable and a desired rolling fatigue life (by the rolling fatigue test in the below-mentioned example, it is a rolling fatigue life more than a 1.0x107 time) will not be acquired. Therefore, the content of Ti was made into 0.002% or less. In addition, as for the content of Ti as an impurity, lessening as much as possible is desirable.
[0031] P:0.02%or less P will be segregated to a grain boundary, and will reduce a rolling fatigue life. If the content exceeds 0.02% especially, the fall of a rolling fatigue life will become remarkable and a desired rolling fatigue life (by the rolling fatigue test in the below-mentioned example, it is a rolling fatigue life more than a 1.0x107 time) will no longer be acquired. Therefore, the content of P was made into 0.02% or less.
[0032] S:0.015%or less S will combine with Mn, will form MnS, and will reduce a rolling fatigue life. If especially the content exceeds 0.015%, since it will become easy to form big and rough MnS, the fall of a rolling fatigue life becomes remarkable, and a desired rolling fatigue life (by the rolling fatigue test in the below-mentioned example, it is a rolling fatigue life more than a 1.0x107 time) is not acquired. Therefore, the content of S was made into 0.015% or less.
[0033] If N combines with Ti or aluminum N:0.009% or less, and it is easy to form TiN and AlN, and N content increases and big and rough TiN and big and rough AlN are formed, a rolling fatigue life will fall. If especially the content exceeds 0.009%, the fall of a rolling fatigue life will become remarkable and a desired rolling fatigue life (by the rolling fatigue test in the below-mentioned example, they are 1.0x107 times or more of rolling fatigue lives) will not be acquired. Therefore, the content of N was made into 0.009% or less.
[0034] O (oxygen):0.0015%or less O will form oxide system inclusion, and will reduce a rolling fatigue life. If especially the content exceeds 0.0015%, the fall of a rolling fatigue life will become remarkable and a desired rolling fatigue life (by the rolling fatigue test in the below-mentioned example, it is a rolling fatigue life more than a 1.0x107 time) will not be acquired. Therefore, the content of O was made into 0.0015% or less. In addition, as for O content as an impurity, lessening as much as possible is desirable.
(B) Specify related this invention of Si, Mn, Cr, and Mo in the amount which fills a formula "5.0 <=1.6x%Si+4.0x%Mn+3.0x%Cr+5.0x%Mo<=9.0" within limits which specified each content of Si, Mn, and Cr by (A). Since it asks by the formula "1.6x%Si+4.0x%Mn+3.0x%Cr+5.0x%Mo" and hardenability runs short of values less than by 5.0 as this shows a next example, the degree of hardness after hardening is low, the fall of a rolling fatigue life becomes remarkable, and a desired rolling fatigue life (it is a rolling fatigue test in the below-mentioned example, and is a rolling fatigue life more than 1.0x107) is not acquired. On the other hand, if the value calculated by the formula "1.6x%Si+4.0x%Mn+3.0x%Cr+5.0x%Mo" exceeds 9.0, hardenability is superfluous, and martensitic structure will generate during cooling after hot rolling, and it will

become easy to generate a quench crack and the crack at the time of handling. Therefore, it considered as the amount which formula "5.0 <=1.6x%Si+4.0x%Mn+3.0x%Cr+5.0x%Mo<=9.0" Fills each content of Si, Mn, and Cr.

[0035] Here, the above-mentioned formula "1.6x%Si+4.0x%Mn+3.0x%Cr+5.0x%Mo" is a formula which this invention person defined for the first time by expressing the hardenability of steel and asking for the multiplier of each element using the least square method based on the following experimental result.

[0036] That is, generally, the hardenability of steel can be searched for by count from the chemical composition and the grain size number of steel as specified also for example, to AISI specification. However, since Mn in a matrix and Cr concentration are falling when it is the steel with which it is high carbon like this invention, and Mn and Cr have condensed in a cementite, the count result and actual hardenability are not in agreement. For this reason, the experiment described below was conducted and the above-mentioned formula was defined as a parameter type which expresses correctly the hardenability of this invention steel with which it is high carbon and Mn and Cr have condensed in a cementite.

[0037] The contents of an experiment: Extract the piece of a steel bar blank test with an outer diameter of 40mm which performed spheroidizing on the same conditions as the "conditions Y" shown in Table 2 similarly mentioned later using each steel shown in Table 1 mentioned later, and it is JISG. The Jominy end quench test was performed based on the approach specified to 0561. The heating conditions of a test piece were considered as the maintenance during 820 degree-Cx 20 minutes which is the general hardening temperature of the components for bearing at that time. Subsequently, the distance from the test piece edge by the side of the refrigerant supply to the location which shows the Rockwell C degree of hardness 50 was found about each steel. And from the content of four elements of Si, Mn, Cr, and Mo which are said to have big effect on the distance of each of this steel for which it asked, and the hardenability of the inside of each element contained in the steel concerned, and steel, it assumed that the effectiveness of each element could be added and the multiplier of each element was calculated with the least square method. Consequently, the multiplier of each element was as being shown in the above-mentioned formula.

(C) Specify the sum density (henceforth Cr+Mn concentration) of Cr and Mn in a cementite to 5.0% or more in sum density this invention of Cr and Mn in a cementite. This is because it does not become 1.3 or more times of the tool life at the time of steel-materials cutting by which the tool life in a cutting trial was manufactured by the general approach since hardening of a cementite was not enough as the Cr+Mn concentration in a cementite is less than 5%, as shown in the below-mentioned example. Furthermore, since it becomes 1.5 or more times of the tool life at the time of steel-materials cutting by which the tool life was manufactured by the general approach when the Cr+Mn concentration in a cementite is 6.0% or more, as for the Cr+Mn concentration in a cementite, it is desirable that it is 6.0% or more. On the other hand, since it may become carbide other than a cementite if the Cr+Mn concentration in a cementite exceeds 15% although especially the upper limit of the Cr+Mn concentration in a cementite is not restricted, as for an upper limit, it is desirable to make it to 15% or less.

[0038] In order to make Cr+Mn concentration in a cementite 5.0% or more, while making the content of Cr and Mn in steel increase, after a matrix metamorphoses into a ferrite from an austenite into spheroidizing, it is effective annealing or to carry out the retention.

[0039] For example, if it cools to 680 degrees C in 10 degrees C /in an hour and cools radiationally out of a furnace after that after holding Steel B (0.90%C-0.50%Mn-0.82% Cr) at 770 degrees C for 2 hours as shown in a next example, the Cr+Mn concentration in a cementite will become 4.2%. Moreover, after cooling to 700 degrees C in 10 degrees C /in an hour after holding at 770 degrees C for 2 hours, it will become 5.8%, if even 650 degrees C is cooled in 5 degrees C /in an hour and it cools radiationally out of a furnace after that. In

addition, at less than 650 degrees C, since diffusion of Cr and Mn becomes very slow, the cooling rate of less than 650 degrees C hardly influences Cr and Mn concentration in a cementite.

[0040] It opted for Cr in a cementite, and measurement of Mn concentration by the following approach. That is, the cementite was taken out with the extraction replica method, by the energy dispersion form X-ray analysis (EDS) attached to a transmission electron microscope (TEM), the concentration of C and Mn in five cementites per each sample was measured, and each of that average was made into the concentration of Cr and Mn in the cementite of the sample.

[0041] Moreover, although especially the particle size of a cementite is not specified, if the mean particle diameter is set to less than 0.4 micrometers, the reinforcement of steel materials will rise and the inclination for the cutting force in cutting to increase and for a tool life to become short will become large. For this reason, as for the mean particle diameter of a cementite, it is desirable that it is 0.4 micrometers or more. Moreover, although especially the upper limit is not specified, either, if the mean particle diameter of a cementite exceeds 0.8 micrometers, since there will be an inclination for the improvement effect of a tool life to also be saturated, the time amount which spheroidizing takes will also become long and productivity will fall, it is desirable [the mean particle diameter of a cementite] that it is 0.8 micrometers or less.

[0042] The mean particle diameter of a cementite is defined as follows. That is, it asks for the area of each cementite grain, asks for the diameter of circle of an area equivalent to the area, and let it be the particle size of the appearance of each cementite grain. Subsequently, the average of the particle size of the appearance of all the cementite grains that measured area is made into apparent cementite mean particle diameter, and what doubled the mean particle diameter of the cementite of the above-mentioned appearance 1.12 is defined as cementite mean particle diameter.

[0043] Cold forging, cold drawing, cutting, etc. are processed into the steel materials (steel-wire material, a steel bar, or steel pipe) of this invention which consists of requirements for a configuration indicated to the above (A), (B), and (C) by the usual approach, and further, after the bearing element components which have a desired mechanical property in response to hardening and heat treatment by annealing at low temperature are made, they are assembled by the bearing as a final product which is a precision machinery component.

[0044] Hereafter, an example explains this invention in more detail.

[0045]

[Example] 18 kinds of steel which has the chemical composition shown in Table 1 was ingoted using the vacuum melting furnace with a capacity of 300kg. The steel of ** mark B-I and O-R is a thing within the limits which chemical composition specifies by this invention among Table 1, and the ** mark A and the steel of J-N are the examples of a comparison from which either of the components separated from the range specified by this invention.

[0046]

[Table 1]

表 1

代符	化学組成（単位：質量%、残部：Feおよび不純物）											計算値
	C	Si	Mn	Cr	Al	Ti	P	S	N	O	その他	X
A	*0.73	0.79	0.49	0.81	0.026	0.0009	0.010	0.009	0.0051	0.0007	−	5.7
B	0.90	0.80	0.50	0.82	0.022	0.0013	0.011	0.007	0.0048	0.0007	−	5.7
C	1.00	0.52	0.40	1.01	0.023	0.0007	0.011	0.010	0.0046	0.0009	−	5.5
D	1.11	0.49	0.41	1.00	0.017	0.0009	0.011	0.010	0.0047	0.0007	−	5.4
E	0.85	0.71	0.80	0.61	0.026	0.0011	0.007	0.009	0.0066	0.0008	−	6.2
F	0.86	0.69	0.40	1.44	0.025	0.0013	0.010	0.007	0.0059	0.0009	−	5.8
G	0.85	1.03	1.09	1.60	0.020	0.0008	0.009	0.008	0.0049	0.0010	−	*10.8
H	0.84	0.51	1.42	1.41	0.024	0.0009	0.011	0.009	0.0051	0.0006	−	*10.7
I	0.86	0.51	0.41	0.64	0.026	0.0012	0.011	0.007	0.0047	0.0009	−	* 4.4
J	0.98	0.68	0.54	1.03	*0.058	0.0010	0.008	0.009	0.0043	0.0008	−	6.3
K	0.99	0.70	0.52	1.01	0.030	*0.0026	0.009	0.006	0.0059	0.0007	−	6.2
L	0.98	0.71	0.53	1.02	0.027	0.0007	*0.027	*0.026	0.0050	0.0009	−	6.3
M	0.99	0.72	0.50	1.00	0.032	0.0008	0.012	0.010	*0.0097	0.0008	−	6.2
N	0.97	0.70	0.52	1.05	0.026	0.0008	0.008	0.012	0.0048	*0.0016	−	6.4
O	0.90	0.61	0.42	1.19	0.021	0.0007	0.010	0.010	0.0046	0.0008	Cu:0.21、Ni:0.34	6.2
P	0.89	0.21	0.40	1.20	0.024	0.0010	0.011	0.008	0.0043	0.0007	Mo:0.17	6.4
Q	0.92	0.59	0.49	1.20	0.024	0.0007	0.015	0.010	0.0045	0.0009	V:0.11、Nb:0.031	6.5
R	0.91	0.60	0.41	1.22	0.022	0.0007	0.009	0.009	0.0047	0.0007	Ca:0.0005、Mg:0.0004	6.3

1)計算値Xは、式「X＝1.6×%Si＋4.0×%Mn＋3.0×%Cr」による計算値である。
2)その他欄に記載しない任意添加元素(Cu, Ni, Mo, V, Nb, Ca, Mg)の含有量は、Cu, Ni, MoおよびV は0.01%未満、Nbは0.001%未満、CaおよびMgは0.0001%未満である。
3)* 印は本発明で規定する範囲から外れていることを示す。

After heating at 1200 degrees C, each steel was cooled radiationally, after carrying out hot forging on the conditions of 950 degrees C of finishing temperature and fabricating to a forging with a diameter [of 40mm], and a die length of about 2450mm. When the appearance of the forging after radiationnal cooling was observed, generating of a minute crack was accepted in the forging of the ** marks G and H, and martensitic structure was intermingled as a result of gazing at the organization. For this reason, future trials were not presented about the forging of the ** marks G and H.
[0047] After cutting the forging which consists of steel of ** mark A-F in which generating of a crack was not accepted, and I-R in die length of 600mm, it performed spheroidizing by each of four kinds of heat treatment conditions (heat pattern) shown in Table 2 using an electric furnace. In addition, a duration until the conditions W in Table 2 are equivalent to the heat pattern of the conventional annealing processing and it results in radiationnal cooling furnace outside is 11 hours. Moreover, for Conditions X, Conditions Y are [Conditions Z of the duration of other conditions] 10 hours for 14 hours for 18 hours.
[0048]
[Table 2]

表 2

<table>
<tr><th rowspan="2">条件</th><th colspan="2">加熱</th><th colspan="2">一次冷却</th><th colspan="2">保定</th><th colspan="2">二次冷却</th><th rowspan="2">その後の冷却</th></tr>
<tr><th>温度 (℃)</th><th>保持時間 (h)</th><th>終了温度 (℃)</th><th>冷却速度 (℃/h)</th><th>温度 (℃)</th><th>保持時間 (h)</th><th>終了温度 (℃)</th><th>冷却速度 (℃/h)</th></tr>
<tr><td>W</td><td rowspan="4">770</td><td rowspan="4">2</td><td>680</td><td rowspan="4">10</td><td>−</td><td>−</td><td>−</td><td>−</td><td rowspan="4">炉外放冷</td></tr>
<tr><td>X</td><td>710</td><td>−</td><td>−</td><td>660</td><td>5</td></tr>
<tr><td>Y</td><td rowspan="2">700</td><td>700</td><td>3</td><td>680</td><td>10</td></tr>
<tr><td>Z</td><td>−</td><td>−</td><td>650</td><td>50</td></tr>
</table>

The grinding process of each forging after spheroidizing was carried out, it was used as the round bar with a diameter of 38mm, and measured the Cr+Mn concentration in a cementite, and the mean particle diameter of a cementite for this.
[0049] That is, after it carried out mirror polishing of the cross section of each round bar,

Cr+Mn concentration took out the cementite with the extraction replica method, by the energy dispersion form X-ray analysis (EDS) attached to a transmission electron microscope (TEM), it measured the concentration of C and Mn in five cementites per each sample, made the average the concentration of Cr and Mn in the cementite of the sample, and totaled and asked for this.
[0050] The mean particle diameter of a cementite carries out the corrosion treatment of the cross section of each round bar which carried out mirror polishing like the above by picral. Ten visual fields on the front face of a corrosion treatment are photoed for 1/2 location of a radius by one 5000 times the scale factor of this from the circle core of each sample using a scanning electron microscope. The diameter which asks for the area of each cementite grain, calculates the circle of an area equivalent to it and is called for by the image analysis according this photograph to the usual approach was made into the diameter of each cementite grain, and the value which doubled the average of that diameter 1.12 was made into the mean particle diameter of a cementite.
[0051] Moreover, the cutting trial was also performed after spheroidizing for each round bar with a diameter of 38mm which carried out the grinding process and which was finished. That is, it is JIS as a cutting tool. G Using the triangular chip which consists of SKH4 specified to 4403, the cutting process by turning was carried out on condition that non-lubrication, peripheral-speed 50 m/min, the amount of slitting of 0.7mm, and delivery 0.2 mm/rev., and the tool life was investigated and it considered as the index of machinability.
[0052] In addition, when a tool life carried out cutting of the round bar on said conditions, till cutting-time 10 minutes, after every 30 seconds and it, the main end cutting-edge abrasion loss of a tool was measured for every minute, and it considered as the time of the main end cutting-edge abrasion loss being set to 0.20mm. Moreover, it was presupposed to the target of machinability that the conditions of the following (b) are satisfied.
(b) 30% or more tool life is a ******** from this on the basis of the tool life of the round bar which carried out spheroidizing on Conditions W about each steel.
[0053] Furthermore, from each round bar with which the above-mentioned cutting was presented, the test piece with a diameter [of 12mm] and a die length of 22mm was cut down, hardening tempering processing (after [the maintenance during 820 degree-Cx 30 minutes] oil-quenching -> annealing of 160 degree-Cx 1-hour maintenance) of this test piece was carried out, and the rolling fatigue test by the following conditions was presented.
[0054] That is, #68 turbine oil specified to a lubricating oil at JIS was used using the cylindrical rolling fatigue tester, and 588MPa(s) and the count of a test piece load performed [Hertz best osculation stress] the rolling fatigue test 46000 times on the conditions which are a part for /. It made the test piece into ten pieces at a time about each steel, and it made the rotational frequency when causing surface exfoliation first in ten test pieces the "rolling fatigue life." A rolling fatigue life is 1.0x107. When it was above, it was estimated that it excelled in the rolling fatigue property.
[0055] Each results of an investigation of the Cr+Mn concentration in the cementite after spheroidizing, the mean particle diameter of a cementite, the tool life in cutting with an engine lathe, and a rolling fatigue life are collectively shown in Table 3 and 4.
[0056]
[Table 3]

表　3

試番	区分	鋼代符	球状化熱処理条件	セメンタイト中のCr＋Mn濃度（質量％）	セメンタイトの平均粒径（μm）	工具寿命（分）	転動疲労寿命（回）
1	比	*A	W	* 3.4	0.41	*12 $	*3.8×10^6
2	比	*A	X	6.4	0.42	19	*4.3×10^6
3	比	*A	Y	6.1	0.42	19	*3.2×10^6
4	比	*A	Z	* 3.2	0.41	*11	*4.0×10^6
5	比	B	W	* 3.2	0.48	* 9 $	2.7×10^7
6	本	B	X	5.8	0.49	13	2.9×10^7
7	本	B	Y	5.7	0.50	12	2.8×10^7
8	比	B	Z	* 3.1	0.48	* 8	3.5×10^7
9	比	C	W	* 3.4	0.55	* 7.5 $	3.9×10^7
10	本	C	X	5.9	0.56	11	3.6×10^7
11	本	C	Y	6.0	0.56	13	4.2×10^7
12	比	C	Z	* 3.3	0.55	* 7	3.8×10^7
13	比	D	W	* 4.0	0.62	* 6.5 $	4.3×10^7
14	本	D	X	5.9	0.63	11	3.9×10^7
15	本	D	Y	5.8	0.62	10	4.7×10^7
16	比	D	Z	* 3.9	0.62	* 6.5	4.1×10^7
17	比	E	W	* 3.8	0.47	* 9.5 $	3.2×10^7
18	本	E	X	5.9	0.48	15	2.9×10^7
19	本	E	Y	5.8	0.48	14	2.8×10^7
20	比	E	Z	* 3.7	0.47	* 9	3.0×10^7
21	比	F	W	* 4.8	0.50	*10 $	2.0×10^7
22	本	F	X	8.2	0.51	19	1.8×10^7
23	本	F	Y	7.8	0.51	17	2.1×10^7
24	比	F	Z	* 4.7	0.50	* 9.5	1.9×10^7
25	比	I	W	* 2.6	0.52	* 6.5 $	*6.2×10^6
26	比	I	X	4.3	0.53	* 8	*5.3×10^6
27	比	I	Y	4.2	0.53	* 7.5	*5.2×10^6
28	比	I	Z	* 2.5	0.52	* 6	*4.0×10^6
29	比	*J	W	* 3.9	0.53	* 7 $	*8.3×10^6
30	比	*J	X	6.9	0.54	14	*9.2×10^6
31	比	*J	Y	6.6	0.54	13	*8.4×10^6
32	比	*J	Z	* 3.7	0.53	* 6.5	*8.7×10^6

1) 区分欄の「本」は本発明例、「比」は比較例を表す。
2) * 印は本発明で規定する範囲から外れていることと、目標に達していないことを示す。
3) $ 印は各鋼における切削性の基準値であることを示す。

[Table 4]

表 4（表3の続き）

試番	区分	鋼代符	球状化熱処理条件	セメンタイト中のCr＋Mn濃度（質量%）	セメンタイトの平均粒径（μm）	工具寿命（分）	転動疲労寿命（回）
33	比	*K	W	* 3.8	0.54	* 6.5 \$	$*3.5\times10^{6}$
34	比	*K	X	6.4	0.55	12	$*3.8\times10^{6}$
35	比	*K	Y	6.3	0.55	12	$*4.3\times10^{6}$
36	比	*K	Z	* 3.7	0.54	* 6	$*3.9\times10^{6}$
37	比	*L	W	* 3.8	0.53	* 8.5 \$	$*9.1\times10^{6}$
38	比	*L	X	6.3	0.54	17	$*8.8\times10^{6}$
39	比	*L	Y	6.4	0.54	18	$*8.4\times10^{6}$
40	比	*L	Z	* 3.7	0.53	* 9	$*8.9\times10^{6}$
41	比	*M	W	* 3.6	0.55	* 5.5 \$	$*8.6\times10^{6}$
42	比	*M	X	6.3	0.56	10	$*8.1\times10^{6}$
43	比	*M	Y	6.2	0.55	9.5	$*9.4\times10^{6}$
44	比	*M	Z	* 3.8	0.54	* 5.5	$*9.2\times10^{6}$
45	比	*N	W	* 4.0	0.52	* 7 \$	$*4.9\times10^{6}$
46	比	*N	X	7.0	0.53	15	$*4.5\times10^{6}$
47	比	*N	Y	6.8	0.53	14	$*4.4\times10^{6}$
48	比	*N	Z	* 3.9	0.52	* 6.5	$*4.6\times10^{6}$
49	比	O	W	* 4.5	0.50	* 9.5 \$	3.4×10^{7}
50	本	O	X	7.4	0.51	18	3.8×10^{7}
51	本	O	Y	7.3	0.51	19	3.1×10^{7}
52	比	O	Z	* 4.4	0.50	* 9	2.9×10^{7}
53	比	P	W	* 4.6	0.50	* 7 \$	5.1×10^{7}
54	本	P	X	7.5	0.50	13	4.5×10^{7}
55	本	P	Y	7.3	0.51	12	4.7×10^{7}
56	比	P	Z	* 4.5	0.50	* 7	7.8×10^{7}
57	比	Q	W	* 4.5	0.53	* 7.5 \$	3.1×10^{7}
58	本	Q	X	7.4	0.54	15	3.8×10^{7}
59	本	Q	Y	7.3	0.53	13	3.3×10^{7}
60	比	Q	Z	* 4.4	0.53	* 7	2.8×10^{7}
61	比	R	W	* 4.6	0.52	*10 \$	4.3×10^{7}
62	本	R	X	7.5	0.53	19	4.5×10^{7}
63	本	R	Y	7.3	0.53	17	4.2×10^{7}
64	比	R	Z	* 4.5	0.52	* 9.5	4.7×10^{7}

1）区分欄の「本」は本発明例、「比」は比較例を表す。
2）* 印は本発明で規定する範囲から外れていることと、目標に達していないことを示す。
3）\$ 印は各鋼における切削性の基準値であることを示す。

The trial using the ** mark A of the example of a comparison, and the steel of I-N so that clearly from Table 3 and 4, that is C content less than 0.8% of ** mark A steel The used test numbers 1-4, the test numbers [value / (X=1.6x%Si+4.0x%Mn+3.0x%Cr+5.0x%Mo) / X] 25-28 using less than 5.0 ** mark I steel, the test numbers 29-32 using the ** mark J steel with which aluminum content exceeds 0.05%, and Ti content 0.002% The ** mark K steel which exceeds The used test numbers 33-36, the test numbers 37-40 using the ** mark L steel with which P content and S content exceed 0.02% and 0.015%, respectively, the test numbers 41-44 using the ** mark M steel with which N content exceeds 0.009%, and O content 0.0015% For the test numbers 45-48 using the ** mark N steel which exceeds, a rolling fatigue life is 1.0x107. A time is not reached.

[0057] Among the above, since the Cr+Mn concentration in a cementite of test numbers 1, 4, 25, 28, 29, 32, 33, 36, and 41, and 44-46 is less than 5.0%, a tool life has not reached a target value, either.

[0058] Moreover, although it is within the limits as which the chemical composition of steel specifies test numbers 5, 8, 9, 12, 13, 16, 17, 20, 21, 24, 49, 52, 53, 56, 57, 60, 61, and 64 by this invention, since the Cr+Mn concentration in a cementite is less than 5.0%, the tool life has not reached a target value.

[0059] On the other hand, for the test numbers 6, 7, 10, 11, 14, 15, 18, 19, 22, 23, 50, 51, 54, 55, 58, 59, 62, and 63 using ** mark B-I and O-R steel which fulfill the conditions specified by this invention, the tool life has reached the target value and, moreover, a rolling fatigue life is

also 1.0x107 of a target. It has exceeded the time.
[0060] Especially the tool life of 6.0% or more of test numbers 11, 22, 23, 50, 51, 54, 55, 57, 60, 61, and 64 has the Cr+Mn concentration as long as 50% or more in a cementite compared with what carried out spheroidizing on Conditions W, and it excels much more.
[0061]
[Effect of the Invention] Its rolling fatigue life is long while the steel materials for bearing element components of this invention are excellent in machinability. For this reason, high life-ization of bearing element components, such as a ball, koro, a needle, a shaft, and a ball race, can be attained.

[Translation done.]

TECHNICAL FIELD

[Field of the Invention] This invention relates to the steel materials for bearing element components excellent in the suitable machinability for the application of bearing element components, such as a ball which constitutes bearing, koro, a needle, a shaft, and a ball race.

[Translation done.]

PRIOR ART

[Description of the Prior Art] Generally as material steel of bearing element components, such as a ball, koro, a needle, a shaft, and a ball race, it is JIS. G High-carbon-chromium bearing steel, such as SUJ2 steel specified to 4805, is used abundantly.
[0003] After the so-called above-mentioned "steel for bearing" is processed with means, such as hot rolling, it receives spheroidizing aiming at softening, subsequently cold forging, cold drawing, cutting, etc. are processed into it, and a desired mechanical property is further given to it in response to hardening and heat treatment by annealing at low temperature.
[0004] The demand to the steel for bearing with which cost was excellent in the machinability which becomes extensible [improvement in cutting speed or a tool life] since cutting increased is very large among each above-mentioned process.
[0005] In free-cutting elements (machinability improvement element), such as Pb and S, if it is made to compound and adds, it is well known by steel independent or that machinability will improve. However, high planar pressure acts on the bearing used for various kinds of industrial machines, automobiles, etc. repeatedly. For this reason, if said free-cutting element is added to the steel for bearing, the rolling fatigue life of bearing (element components) will fall sharply. Furthermore, generally said free-cutting element reduces hot-working nature. Therefore, there is also a problem of becoming easy to generate a surface check and a crack, at the time of hot working, such as hot rolling.
[0006] For this reason, the "excellent in machinability high Si-low Cr bearing steel" which made REM (rare earth elements) contain in steel is indicated by JP,1-255651,A. However, the yield of REM in the inside of steel is unstable in order to tend [very] to oxidize. Moreover, it is industrially difficult to control the particle size and the distributed condition of the REM oxide which is easy to generate in steel. If a big and rough REM oxide generates or a REM oxide generates so much, a rolling fatigue life will fall sharply.
[0007] "The bearing steel excellent in machinability" which raises machinability is indicated by JP,3-56641,A, without reducing a rolling fatigue life by making BN compound generate into steel. However, since the solubility to the inside of steel is small, the yield of B in the inside of steel is unstable, and it also tends to produce a segregation. Furthermore, since B reduces the coagulation initiation temperature of high-carbon steel remarkably, solidifying segregation will be conjointly promoted with the segregation of B. In addition, the fall of coagulation initiation temperature leads to the fall of hot-working nature, and it becomes easy to generate a surface check and a crack at the time of hot working. Therefore, it was not not necessarily being stabilized on a scale of industrial as for 0.004 - 0.020%, and being able to manufacture bearing element components with the value to which B content of the steel for bearing was specified in said official report even if, i.e., mass %,, either.
[0008] "The bearing steel which is excellent in machinability and cold-working nature and its manufacture approach" of heat-treating in JP,9-227991,A on condition that specification, and adjusting the number of carbide and hardness under organization to it are indicated. However,

it is necessary to perform gradual heating or isothermal maintenance in the middle of a heating process on the annealing conditions proposed in this official report. For this reason, annealing time amount becomes long and causes the fall of productivity. Furthermore, when being aimed at the rolling-up coil which is the general configuration of steel-wire material ("steel-wire material" is only hereafter called "wire rod") since heat treatment conditions need to be changed, such as gradual heating, rapid heating, and annealing, for example, it is difficult to heat-treat the whole coil to homogeneity (annealing processing). It will be difficult to carry out annealing on the conditions as which the continuation heat treating furnace used on a scale of industrial was specified in said official report since the temperature of each zone was generally decided and the number of zones was also restricted, even if it can perform uniform heat treatment, in order to anneal by the provision, a continuation heat treating furnace will need reconstruction and updating, and cost will increase.
[0009] According to the technique proposed in each above-mentioned official report, the steel materials and concrete target which were excellent in ******** once can get a wire rod, a steel bar, and a steel pipe. However, as already stated, there were productivity and a big problem in respect of quality.

[Translation done.]

EFFECT OF THE INVENTION

[Effect of the Invention] Its rolling fatigue life is long while the steel materials for bearing element components of this invention are excellent in machinability. For this reason, high life-ization of bearing element components, such as a ball, koro, a needle, a shaft, and a ball race, can be attained.

[Translation done.]

TECHNICAL PROBLEM

[Problem(s) to be Solved by the Invention] It is offering the steel materials (a wire rod, a steel bar, or steel pipe) excellent in the suitable machinability for the application of bearing element components, such as a ball, koro, a needle, a shaft, and a ball race, without causing the fall of productivity, without having made this invention in view of the above-mentioned present condition, and the purpose carrying out addition content of the free-cutting element specially, since annealing time amount is also the about 10 - 20 same hours as usual.
[0011] In addition, it is 1.0x107 by the rolling fatigue test in the below-mentioned example since high planar pressure acts on bearing repeatedly as already stated. It aims at having a rolling fatigue life more than a time.

[Translation done.]

MEANS

[Means for Solving the Problem] The summary of this invention is in the steel materials for bearing element components excellent in the following machinability.
[0013] By mass %, C:0.8 - 1.2%, Si:0.2-2.0%, Mn:0.2-1.5%, Cr: 0.6-2.0%, less than [aluminum:0.05%], less than [Cu:2.0%], nickel: Less than [4.0%], less than [Mo:0.5%], V:0.2% or less, less than [Nb:0.10%], Contain less than [calcium:0.003%] and less than [Mg:0.003%], and the remainder consists of Fe and an impurity. For 0.002% or less and P, 0.02% or less and S are [Ti in an impurity / 0.009% or less and O (oxygen) of 0.015% or less and N] 0.0015% or less. The steel materials for bearing element components excellent in the machinability which the relation between Si, Mn, Cr, and Mo fills a formula "5.0 <=1.6x% Si+4.0x%Mn+3.0x%Cr+5.0x%Mo<=9.0", and is characterized by the sum density of Cr and Mn in a cementite being 5.0% or more.
[0014] In above-mentioned this invention, about seven elements of Cu, nickel, Mo, V, Nb, calcium, and Mg, addition content may not necessarily be carried out among each above-mentioned element, and you may be the amount level of impurities. Moreover, the steel materials said to this invention mean a wire rod, a steel bar, or a steel pipe.
[0015] this invention persons repeated investigation and research about the effect the organization after spheroidizing of a wire rod, a steel bar, and a steel pipe, Cr in a cementite, Mn concentration, and cementite particle size affect machinability, consequently acquired the following knowledge.
(a) In cutting of the steel for bearing, the hardness of the carbide in cut material influences a tool life and upper limit cutting speed greatly.
(b) If Cr and Mn condense in a cementite, it is known that a cementite will harden, but if Cr in the ferrite which is a matrix, and Mn decrease, the more it softens and the hardness difference of a cementite and the ferrite which is a matrix becomes large, the more machinability of a ferrite will improve.
(c) in order to raise Cr in a cementite, and Mn concentration, after metamorphosing into a ferrite from an austenite into spheroidizing -- annealing -- or what is necessary is just to carry out the retention
(d) What is necessary is for the hardenability more than fixed to need to be secured, in order to secure a rolling fatigue life, and just to control the content of Si, Mn, Cr, and Mo for that purpose.
[0016] This invention is completed based on the above-mentioned knowledge.
[0017]
[Embodiment of the Invention] Hereafter, this invention is explained in detail. In addition, "mass %" is meant"%" below.
(A) Although C:0.8 - 1.2% of chemical composition C performs hardening and heat treatment by annealing at low temperature and a desired mechanical property is made to give the steel materials for bearing (bearing element components), the content of the degree of hardness

after hardening annealing is low at less than 0.8%, and a desired rolling fatigue life (it is a rolling fatigue test in the below-mentioned example, and is a rolling fatigue life more than a 1.0x107 time) is not acquired. On the other hand, if the content of C exceeds 1.2%, the coagulation initiation temperature of steel falls, and when steel materials are steel pipes especially at the time of hot working, a crack and cracks will occur frequently at the time of tube manufacturing between heat. Moreover, since it becomes easy to generate huge carbide at the time of the coagulation of steel, when not performing homogenization heat treatment of long duration, a target rolling fatigue life is not acquired. Therefore, C content was made into 0.8 - 1.2%. The desirable range is 0.8 - 1.0%, and the more desirable range is 0.8 - 0.9%.
[0018] Si: 0.2 - 2.0%Si is an element effective in raising a rolling fatigue life, and also is also an element required as a deoxidizer. Moreover, Si is also the element which raises the hardenability of steel. However, at less than 0.2%, the effectiveness of the above [the content] is difficult to get. In addition, if the content of Si becomes 0.6% or more, the improvement effectiveness in machinability will also become large. On the other hand, if the content of Si exceeds 2.0%, since long duration is required in order to carry out descaling after hot rolling and spheroidizing, the sharp fall of productivity will be caused. Therefore, Si content was made into 0.2 - 2.0%. The desirable range is 0.5 - 1.5%, and the more desirable range is 0.5 - 1.0%.
[0019] Mn: It is an element required for prevention of the hot shortness by S at the same time Mn raises the hardenability of steel 0.2 to 1.5%. In order to demonstrate such effectiveness, it is necessary to make Mn contain 0.2% or more. On the other hand, if the content of Mn exceeds 1.0%, the main segregation of not only Mn but C will come to arise, and if it exceeds 1.5%, the main segregation of Mn and C will become remarkable and will cause the fall of a rolling fatigue life. Therefore, Mn content was made into 0.2 - 1.5%. The desirable range is 0.2 - 1.0%, and the more desirable range is 0.2 - 0.8%.
[0020] Cr: 0.6-2.0%Cr is the element which is easy to condense in a cementite, stiffens a cementite and raises machinability at the same time it raises the hardenability of steel. However, at less than 0.6%, the effectiveness of the above [the content] is difficult to get. On the other hand, if it exceeds 1.6%, the main segregation of not only Cr but C element will come to arise, and if it exceeds 2.0%, the main segregation of Cr and C will become remarkable and will cause the fall of a rolling fatigue life. Therefore, Cr content was made into 0.6 - 2.0%. The desirable range is 0.6 - 1.6%, and the more desirable range is 0.6 - 1.3%.
[0021] aluminum: Although aluminum is added as a deoxidizer 0.05% or less, superfluous aluminum forms nonmetal system inclusion and please give me a rolling fatigue life low. If the content exceeds 0.05% especially, big and rough nonmetal system inclusion will be formed, the remarkable fall of a rolling fatigue life will be caused, and a desired rolling fatigue life (by the rolling fatigue test in the below-mentioned example, it is a rolling fatigue life more than a 1.0x107 time) will no longer be acquired. Therefore, the content of aluminum was made into 0.05% or less. A desirable upper limit is 0.04% and a more desirable upper limit is 0.03%. On the other hand, in order to acquire sufficient deoxidation effectiveness, it is good to make the content into 0.0003% or more. In addition, when deoxidation is fully made by the above-mentioned Si, it is not necessary to necessarily add aluminum, and the content may be the amount level of impurities.
[0022] Cu: Less than [2.0%] (the desirable range at the time of addition is 0.05 - 2.0%)
It is not necessary to add Cu. If it adds, there is an operation which raises corrosion resistance. In order to acquire this effectiveness certainly, as for Cu, it is desirable to consider as 0.05% or more of content. However, if the content exceeds 2.0%, it will segregate to the grain boundary and the crack at the time of hot working, such as slabbing of a steel ingot and hot rolling of a wire rod, and generating of a crack will become remarkable. Therefore, the content of Cu was made into 2.0% or less. A desirable upper limit is 1.5% and a more desirable upper limit is

1.0%.
[0023] nickel: Less than [4.0%] (the desirable range at the time of addition is 0.2 - 4.0%)
It is not necessary to add nickel. If it adds, it has the operation which dissolves in the martensite after hardening and raises toughness. In order to acquire this effectiveness certainly, as for nickel, it is desirable to consider as 0.2% or more of content. However, even if it makes it contain exceeding 4.0%, the aforementioned effectiveness is saturated and cost just increases. Therefore, the content of nickel was made into 4.0% or less. A desirable upper limit is 3.0% and a more desirable upper limit is 2.0%.
[0024] Mo: Less than [0.5%] (the desirable range at the time of addition is 0.05 - 0.5%)
It is not necessary to also add Mo. If it adds, there is an operation which raises hardenability and raises a rolling fatigue life. In order to acquire this effectiveness certainly, as for Mo, it is desirable to consider as 0.05% or more of content. However, if the content exceeds 0.5%, hardenability will become high too much, and it will become easy to generate martensite after hot rolling, and will become easy to generate a crack. Therefore, the content of Mo was made into 0.5% or less. A desirable upper limit is 0.3% and a more desirable upper limit is 0.2%.
[0025] V:0.2% or less (the desirable range at the time of addition is 0.03 - 0.2%)
It is not necessary to add V. If it adds, austenite crystal grain is made to make it detailed, and it has the operation which raises toughness. In order to acquire this effectiveness certainly, as for V, it is desirable to consider as 0.03% or more of content. However, even if it makes it contain exceeding 0.2%, the aforementioned effectiveness is saturated and cost just increases. Therefore, the content of V was made into 0.2% or less. A desirable upper limit is 0.1%.
[0026] Nb: Less than [0.10%] (the desirable range at the time of addition is 0.01 - 0.10%)
It is not necessary to add Nb. If it adds, austenite crystal grain is made to make it detailed, and it has the operation which raises toughness. In order to acquire this effectiveness certainly, as for Nb, it is desirable to consider as 0.01% or more of content. However, even if it makes it contain exceeding 0.10%, the aforementioned effectiveness is saturated and cost just increases. Therefore, the content of Nb was made into 0.10% or less. A desirable upper limit is 0.08% and a more desirable upper limit is 0.05%.
[0027] calcium: It is not necessary to add calcium 0.003% or less. If it adds, it has the operation which raises hot-working nature. In order to acquire this effectiveness certainly, as for calcium, it is desirable to consider as 0.0001% or more of content. However, even if it makes calcium contain exceeding 0.003%, the aforementioned effectiveness is saturated and cost just increases. Therefore, the content of calcium was made into 0.003% or less. A desirable upper limit is 0.002%.
[0028] Mg: It is not necessary to also add Mg 0.003% or less. If it adds, it has the operation which raises hot-working nature. In order to acquire this effectiveness certainly, as for Mg, it is desirable to consider as 0.0001% or more of content. However, even if it makes Mg contain exceeding 0.003%, the aforementioned effectiveness is saturated and cost just increases. Therefore, the content of Mg was made into 0.003% or less. A desirable upper limit is 0.002%.
[0029] In this invention, it is important to restrict the content of Ti, P, S, N, and O (oxygen) as an impurity as follows. The reason is as follows.
[0030] Ti: 0.002%or less Ti will combine with N, will form TiN, and will reduce a rolling fatigue life. If especially the content exceeds 0.002%, the fall of a rolling fatigue life will become remarkable and a desired rolling fatigue life (by the rolling fatigue test in the below-mentioned example, it is a rolling fatigue life more than a 1.0x107 time) will not be acquired. Therefore, the content of Ti was made into 0.002% or less. In addition, as for the content of Ti as an impurity, lessening as much as possible is desirable.
[0031] P:0.02%or less P will be segregated to a grain boundary, and will reduce a rolling fatigue life. If the content exceeds 0.02% especially, the fall of a rolling fatigue life will become

remarkable and a desired rolling fatigue life (by the rolling fatigue test in the below-mentioned example, it is a rolling fatigue life more than a 1.0x107 time) will no longer be acquired. Therefore, the content of P was made into 0.02% or less.
[0032] S:0.015%or less S will combine with Mn, will form MnS, and will reduce a rolling fatigue life. If especially the content exceeds 0.015%, since it will become easy to form big and rough MnS, the fall of a rolling fatigue life becomes remarkable, and a desired rolling fatigue life (by the rolling fatigue test in the below-mentioned example, it is a rolling fatigue life more than a 1.0x107 time) is not acquired. Therefore, the content of S was made into 0.015% or less.
[0033] If N combines with Ti or aluminum N:0.009% or less, and it is easy to form TiN and AlN, and N content increases and big and rough TiN and big and rough AlN are formed, a rolling fatigue life will fall. If especially the content exceeds 0.009%, the fall of a rolling fatigue life will become remarkable and a desired rolling fatigue life (by the rolling fatigue test in the below-mentioned example, they are 1.0x107 times or more of rolling fatigue lives) will not be acquired. Therefore, the content of N was made into 0.009% or less.
[0034] O (oxygen):0.0015%or less O will form oxide system inclusion, and will reduce a rolling fatigue life. If especially the content exceeds 0.0015%, the fall of a rolling fatigue life will become remarkable and a desired rolling fatigue life (by the rolling fatigue test in the below-mentioned example, it is a rolling fatigue life more than a 1.0x107 time) will not be acquired. Therefore, the content of O was made into 0.0015% or less. In addition, as for O content as an impurity, lessening as much as possible is desirable.
(B) Specify related this invention of Si, Mn, Cr, and Mo in the amount which fills a formula "5.0 <=1.6x%Si+4.0x%Mn+3.0x%Cr+5.0x%Mo<=9.0" within limits which specified each content of Si, Mn, and Cr by (A). Since it asks by the formula "1.6x%Si+4.0x%Mn+3.0x%Cr+5.0x%Mo" and hardenability runs short of values less than by 5.0 as this shows a next example, the degree of hardness after hardening is low, the fall of a rolling fatigue life becomes remarkable, and a desired rolling fatigue life (it is a rolling fatigue test in the below-mentioned example, and is a rolling fatigue life more than 1.0x107) is not acquired. On the other hand, if the value calculated by the formula "1.6x%Si+4.0x%Mn+3.0x%Cr+5.0x%Mo" exceeds 9.0, hardenability is superfluous, and martensitic structure will generate during cooling after hot rolling, and it will become easy to generate a quench crack and the crack at the time of handling. Therefore, it considered as the amount which formula "5.0 <=1.6x%Si+4.0x%Mn+3.0x%Cr+5.0x%Mo<=9.0" Fills each content of Si, Mn, and Cr.
[0035] Here, the above-mentioned formula "1.6x%Si+4.0x%Mn+3.0x%Cr+5.0x%Mo" is a formula which this invention person defined for the first time by expressing the hardenability of steel and asking for the multiplier of each element using the least square method based on the following experimental result.
[0036] That is, generally, the hardenability of steel can be searched for by count from the chemical composition and the grain size number of steel as specified also for example, to AISI specification. However, since Mn in a matrix and Cr concentration are falling when it is the steel with which it is high carbon like this invention, and Mn and Cr have condensed in a cementite, the count result and actual hardenability are not in agreement. For this reason, the experiment described below was conducted and the above-mentioned formula was defined as a parameter type which expresses correctly the hardenability of this invention steel with which it is high carbon and Mn and Cr have condensed in a cementite.
[0037] The contents of an experiment: Extract the piece of a steel bar blank test with an outer diameter of 40mm which performed spheroidizing on the same conditions as the "conditions Y" shown in Table 2 similarly mentioned later using each steel shown in Table 1 mentioned later, and it is JISG. The Jominy end quench test was performed based on the approach specified to 0561. The heating conditions of a test piece were considered as the maintenance during 820 degree-Cx 20 minutes which is the general hardening temperature of the components for

bearing at that time. Subsequently, the distance from the test piece edge by the side of the refrigerant supply to the location which shows the Rockwell C degree of hardness 50 was found about each steel. And from the content of four elements of Si, Mn, Cr, and Mo which are said to have big effect on the distance of each of this steel for which it asked, and the hardenability of the inside of each element contained in the steel concerned, and steel, it assumed that the effectiveness of each element could be added and the multiplier of each element was calculated with the least square method. Consequently, the multiplier of each element was as being shown in the above-mentioned formula.
(C) Specify the sum density (henceforth Cr+Mn concentration) of Cr and Mn in a cementite to 5.0% or more in sum density this invention of Cr and Mn in a cementite. This is because it does not become 1.3 or more times of the tool life at the time of steel-materials cutting by which the tool life in a cutting trial was manufactured by the general approach since hardening of a cementite was not enough as the Cr+Mn concentration in a cementite is less than 5%, as shown in the below-mentioned example. Furthermore, since it becomes 1.5 or more times of the tool life at the time of steel-materials cutting by which the tool life was manufactured by the general approach when the Cr+Mn concentration in a cementite is 6.0% or more, as for the Cr+Mn concentration in a cementite, it is desirable that it is 6.0% or more. On the other hand, since it may become carbide other than a cementite if the Cr+Mn concentration in a cementite exceeds 15% although especially the upper limit of the Cr+Mn concentration in a cementite is not restricted, as for an upper limit, it is desirable to make it to 15% or less.
[0038] In order to make Cr+Mn concentration in a cementite 5.0% or more, while making the content of Cr and Mn in steel increase, after a matrix metamorphoses into a ferrite from an austenite into spheroidizing, it is effective annealing or to carry out the retention.
[0039] For example, if it cools to 680 degrees C in 10 degrees C /in an hour and cools radiationally out of a furnace after that after holding Steel B (0.90%C-0.50%Mn-0.82% Cr) at 770 degrees C for 2 hours as shown in a next example, the Cr+Mn concentration in a cementite will become 4.2%. Moreover, after cooling to 700 degrees C in 10 degrees C /in an hour after holding at 770 degrees C for 2 hours, it will become 5.8%, if even 650 degrees C is cooled in 5 degrees C /in an hour and it cools radiationally out of a furnace after that. In addition, at less than 650 degrees C, since diffusion of Cr and Mn becomes very slow, the cooling rate of less than 650 degrees C hardly influences Cr and Mn concentration in a cementite.
[0040] It opted for Cr in a cementite, and measurement of Mn concentration by the following approach. That is, the cementite was taken out with the extraction replica method, by the energy dispersion form X-ray analysis (EDS) attached to a transmission electron microscope (TEM), the concentration of C and Mn in five cementites per each sample was measured, and each of that average was made into the concentration of Cr and Mn in the cementite of the sample.
[0041] Moreover, although especially the particle size of a cementite is not specified, if the mean particle diameter is set to less than 0.4 micrometers, the reinforcement of steel materials will rise and the inclination for the cutting force in cutting to increase and for a tool life to become short will become large. For this reason, as for the mean particle diameter of a cementite, it is desirable that it is 0.4 micrometers or more. Moreover, although especially the upper limit is not specified, either, if the mean particle diameter of a cementite exceeds 0.8 micrometers, since there will be an inclination for the improvement effect of a tool life to also be saturated, the time amount which spheroidizing takes will also become long and productivity will fall, it is desirable [the mean particle diameter of a cementite] that it is 0.8 micrometers or less.
[0042] The mean particle diameter of a cementite is defined as follows. That is, it asks for the area of each cementite grain, asks for the diameter of circle of an area equivalent to the area,

and let it be the particle size of the appearance of each cementite grain. Subsequently, the average of the particle size of the appearance of all the cementite grains that measured area is made into apparent cementite mean particle diameter, and what doubled the mean particle diameter of the cementite of the above-mentioned appearance 1.12 is defined as cementite mean particle diameter.
[0043] Cold forging, cold drawing, cutting, etc. are processed into the steel materials (steel-wire material, a steel bar, or steel pipe) of this invention which consists of requirements for a configuration indicated to the above (A), (B), and (C) by the usual approach, and further, after the bearing element components which have a desired mechanical property in response to hardening and heat treatment by annealing at low temperature are made, they are assembled by the bearing as a final product which is a precision machinery component.
[0044] Hereafter, an example explains this invention in more detail.

[Translation done.]

* NOTICES *

EXAMPLE

[Example] 18 kinds of steel which has the chemical composition shown in Table 1 was ingoted using the vacuum melting furnace with a capacity of 300kg. The steel of ** mark B-I and O-R is a thing within the limits which chemical composition specifies by this invention among Table 1, and the ** mark A and the steel of J-N are the examples of a comparison from which either of the components separated from the range specified by this invention.
[0046]
[Table 1]

表 1

代符	化学組成（単位：質量%、残部：Feおよび不純物）											計算値 X
	C	Si	Mn	Cr	Al	Ti	P	S	N	O	その他	
A	*0.73	0.79	0.49	0.81	0.026	0.0009	0.010	0.009	0.0051	0.0007	—	5.7
B	0.90	0.80	0.50	0.82	0.022	0.0013	0.011	0.007	0.0048	0.0007	—	5.7
C	1.00	0.52	0.40	1.01	0.023	0.0007	0.011	0.010	0.0046	0.0009	—	5.5
D	1.11	0.49	0.41	1.00	0.017	0.0009	0.011	0.010	0.0047	0.0007	—	5.4
E	0.85	0.71	0.80	0.61	0.026	0.0011	0.007	0.009	0.0066	0.0008	—	6.2
F	0.86	0.69	0.40	1.44	0.025	0.0013	0.010	0.007	0.0059	0.0009	—	5.8
G	0.85	1.03	1.09	1.60	0.020	0.0008	0.009	0.008	0.0049	0.0010	—	*10.8
H	0.84	0.51	1.42	1.41	0.024	0.0009	0.011	0.009	0.0051	0.0006	—	*10.7
I	0.86	0.51	0.41	0.64	0.026	0.0012	0.011	0.007	0.0047	0.0009	—	* 4.4
J	0.98	0.68	0.54	1.03	*0.058	0.0010	0.008	0.009	0.0043	0.0008	—	6.3
K	0.99	0.70	0.52	1.01	0.030	*0.0026	0.009	0.006	0.0059	0.0007	—	6.2
L	0.98	0.71	0.53	1.02	0.027	0.0007	*0.027	*0.026	0.0050	0.0009	—	6.3
M	0.99	0.72	0.50	1.00	0.032	0.0008	0.012	0.010	*0.0097	0.0008	—	6.2
N	0.97	0.70	0.52	1.05	0.026	0.0008	0.008	0.012	0.0048	*0.0016	—	6.4
O	0.90	0.61	0.42	1.19	0.021	0.0007	0.010	0.010	0.0046	0.0008	Cu:0.21、Ni:0.34	6.2
P	0.89	0.21	0.40	1.20	0.024	0.0010	0.011	0.008	0.0043	0.0007	Mo:0.17	6.4
Q	0.92	0.59	0.49	1.20	0.024	0.0007	0.015	0.010	0.0045	0.0009	V:0.11、Nb:0.031	6.5
R	0.91	0.60	0.41	1.22	0.022	0.0007	0.009	0.009	0.0047	0.0007	Ca:0.0005、Mg:0.0004	6.3

1)計算値Xは、式「X=1.6×%Si+4.0×%Mn+3.0×%Cr」による計算値である。
2)その他欄に記載しない任意添加元素(Cu, Ni, Mo, V, Nb, Ca, Mg)の含有量は、Cu, Ni, MoおよびV は0.01%未満、Nbは0.001%未満、CaおよびMgは0.0001%未満である。
3)* 印は本発明で規定する範囲から外れていることを示す。

After heating at 1200 degrees C, each steel was cooled radiationally, after carrying out hot forging on the conditions of 950 degrees C of finishing temperature and fabricating to a forging with a diameter [of 40mm], and a die length of about 2450mm. When the appearance of the forging after radiationnal cooling was observed, generating of a minute crack was accepted in the forging of the ** marks G and H, and martensitic structure was intermingled as a result of gazing at the organization. For this reason, future trials were not presented about the forging of the ** marks G and H.
[0047] After cutting the forging which consists of steel of ** mark A-F in which generating of a crack was not accepted, and I-R in die length of 600mm, it performed spheroidizing by each of

four kinds of heat treatment conditions (heat pattern) shown in Table 2 using an electric furnace. In addition, a duration until the conditions W in Table 2 are equivalent to the heat pattern of the conventional annealing processing and it results in radiationnal cooling furnace outside is 11 hours. Moreover, for Conditions X, Conditions Y are [Conditions Z of the duration of other conditions] 10 hours for 14 hours for 18 hours.
[0048]
[Table 2]

表 2

条件	加熱		一次冷却		保定		二次冷却		その後の冷却
	温度 (℃)	保持時間 (h)	終了温度 (℃)	冷却速度 (℃/h)	温度 (℃)	保持時間 (h)	終了温度 (℃)	冷却速度 (℃/h)	
W	770	2	680	10	–	–	–	–	炉外放冷
X			710		–	–	660	5	
Y			700		700	3	680	10	
Z					–	–	650	50	

The grinding process of each forging after spheroidizing was carried out, it was used as the round bar with a diameter of 38mm, and measured the Cr+Mn concentration in a cementite, and the mean particle diameter of a cementite for this.
[0049] That is, after it carried out mirror polishing of the cross section of each round bar, Cr+Mn concentration took out the cementite with the extraction replica method, by the energy dispersion form X-ray analysis (EDS) attached to a transmission electron microscope (TEM), it measured the concentration of C and Mn in five cementites per each sample, made the average the concentration of Cr and Mn in the cementite of the sample, and totaled and asked for this.
[0050] The mean particle diameter of a cementite carries out the corrosion treatment of the cross section of each round bar which carried out mirror polishing like the above by picral. Ten visual fields on the front face of a corrosion treatment are photoed for 1/2 location of a radius by one 5000 times the scale factor of this from the circle core of each sample using a scanning electron microscope. The diameter which asks for the area of each cementite grain, calculates the circle of an area equivalent to it and is called for by the image analysis according this photograph to the usual approach was made into the diameter of each cementite grain, and the value which doubled the average of that diameter 1.12 was made into the mean particle diameter of a cementite.
[0051] Moreover, the cutting trial was also performed after spheroidizing for each round bar with a diameter of 38mm which carried out the grinding process and which was finished. That is, it is JIS as a cutting tool. G Using the triangular chip which consists of SKH4 specified to 4403, the cutting process by turning was carried out on condition that non-lubrication, peripheral-speed 50 m/min, the amount of slitting of 0.7mm, and delivery 0.2 mm/rev., and the tool life was investigated and it considered as the index of machinability.
[0052] In addition, when a tool life carried out cutting of the round bar on said conditions, till cutting-time 10 minutes, after every 30 seconds and it, the main end cutting-edge abrasion loss of a tool was measured for every minute, and it considered as the time of the main end cutting-edge abrasion loss being set to 0.20mm. Moreover, it was presupposed to the target of machinability that the conditions of the following (b) are satisfied.
(b) 30% or more tool life is a ******** from this on the basis of the tool life of the round bar which carried out spheroidizing on Conditions W about each steel.
[0053] Furthermore, from each round bar with which the above-mentioned cutting was presented, the test piece with a diameter [of 12mm] and a die length of 22mm was cut down, hardening tempering processing (after [the maintenance during 820 degree-Cx 30 minutes]

oil-quenching -> annealing of 160 degree-Cx 1-hour maintenance) of this test piece was carried out, and the rolling fatigue test by the following conditions was presented.
[0054] That is, #68 turbine oil specified to a lubricating oil at JIS was used using the cylindrical rolling fatigue tester, and 588MPa(s) and the count of a test piece load performed [Hertz best osculation stress] the rolling fatigue test 46000 times on the conditions which are a part for /. It made the test piece into ten pieces at a time about each steel, and it made the rotational frequency when causing surface exfoliation first in ten test pieces the "rolling fatigue life." A rolling fatigue life is 1.0x107. When it was above, it was estimated that it excelled in the rolling fatigue property.
[0055] Each results of an investigation of the Cr+Mn concentration in the cementite after spheroidizing, the mean particle diameter of a cementite, the tool life in cutting with an engine lathe, and a rolling fatigue life are collectively shown in Table 3 and 4.
[0056]
[Table 3]

表 3

試番	区分	鋼代符	球状化熱処理条件	ｾﾒﾝﾀｲﾄ中のCr＋Mn濃度（質量%）	ｾﾒﾝﾀｲﾄの平均粒径（μm）	工具寿命（分）	転動疲労寿命（回）
1	比	*A	W	* 3.4	0.41	*12 $	*3.8×10^6
2	比	*A	X	6.4	0.42	19	*4.3×10^6
3	比	*A	Y	6.1	0.42	19	*3.2×10^6
4	比	*A	Z	* 3.2	0.41	*11	*4.0×10^6
5	比	B	W	* 3.2	0.48	* 9 $	2.7×10^7
6	本	B	X	5.8	0.49	13	2.9×10^7
7	本	B	Y	5.7	0.50	12	2.8×10^7
8	比	B	Z	* 3.1	0.48	* 8	3.5×10^7
9	比	C	W	* 3.4	0.55	* 7.5 $	3.9×10^7
10	本	C	X	5.9	0.56	11	3.6×10^7
11	本	C	Y	6.0	0.56	13	4.2×10^7
12	比	C	Z	* 3.3	0.55	* 7	3.8×10^7
13	比	D	W	* 4.0	0.62	* 6.5 $	4.3×10^7
14	本	D	X	5.9	0.63	11	3.9×10^7
15	本	D	Y	5.8	0.62	10	4.7×10^7
16	比	D	Z	* 3.9	0.62	* 6.5	4.1×10^7
17	比	E	W	* 3.8	0.47	* 9.5 $	3.2×10^7
18	本	E	X	5.9	0.48	15	2.9×10^7
19	本	E	Y	6.8	0.48	14	2.8×10^7
20	比	E	Z	* 3.7	0.47	* 9	3.0×10^7
21	比	F	W	* 4.8	0.50	*10 $	2.0×10^7
22	本	F	X	8.2	0.51	19	1.8×10^7
23	本	F	Y	7.8	0.51	17	2.1×10^7
24	比	F	Z	* 4.7	0.50	* 9.5	1.9×10^7
25	比	I	W	* 2.6	0.52	* 6.5 $	*6.2×10^6
26	比	I	X	4.3	0.53	* 8	*5.3×10^6
27	比	I	Y	4.2	0.53	* 7.5	*5.2×10^6
28	比	I	Z	* 2.5	0.52	* 6	*4.0×10^6
29	比	*J	W	* 3.9	0.53	* 7 $	*8.3×10^6
30	比	*J	X	6.9	0.54	14	*9.2×10^6
31	比	*J	Y	6.6	0.54	13	*8.4×10^6
32	比	*J	Z	* 3.7	0.53	* 6.5	*8.7×10^6

1) 区分欄の「本」は本発明例、「比」は比較例を表す。
2) *印は本発明で規定する範囲から外れていることと、目標に達していないことを示す。
3) $印は各鋼における切削性の基準値であることを示す。

[Table 4]

表 4（表3の続き）

試番	区分	鋼代符	球状化熱処理条件	セメンタイト中のCr+Mn濃度（質量%）	セメンタイトの平均粒径（μm）	工具寿命（分）	転動疲労寿命（回）
33	比	*K	W	* 3.8	0.54	* 6.5 $	*3.5×10^6
34	比	*K	X	6.4	0.55	12	*3.8×10^6
35	比	*K	Y	6.3	0.55	12	*4.3×10^6
36	比	*K	Z	* 3.7	0.54	* 6	*3.9×10^6
37	比	*L	W	* 3.8	0.53	* 8.5 $	*9.1×10^6
38	比	*L	X	6.3	0.54	17	*8.8×10^6
39	比	*L	Y	6.4	0.54	18	*8.4×10^6
40	比	*L	Z	* 3.7	0.53	* 9	*8.9×10^6
41	比	*M	W	* 3.6	0.55	* 5.5 $	*8.6×10^6
42	比	*M	X	6.3	0.56	10	*8.1×10^6
43	比	*M	Y	6.2	0.55	9.5	*9.4×10^6
44	比	*M	Z	* 3.8	0.54	* 5.5	*9.2×10^6
45	比	*N	W	* 4.0	0.52	* 7 $	*4.9×10^6
46	比	*N	X	7.0	0.53	15	*4.5×10^6
47	比	*N	Y	6.8	0.53	14	*4.4×10^6
48	比	*N	Z	* 3.9	0.52	* 6.5	*4.6×10^6
49	比	O	W	* 4.5	0.50	* 9.5 $	3.4×10^7
50	本	O	X	7.4	0.51	19	3.8×10^7
51	本	O	Y	7.3	0.51	19	3.1×10^7
52	比	O	Z	* 4.4	0.50	* 9	2.9×10^7
53	比	P	W	* 4.6	0.50	* 7 $	5.1×10^7
54	本	P	X	7.5	0.50	13	4.5×10^7
55	本	P	Y	7.3	0.51	12	4.7×10^7
56	比	P	Z	* 4.5	0.50	* 7	7.8×10^7
57	比	Q	W	* 4.5	0.53	* 7.5 $	3.1×10^7
58	本	Q	X	7.4	0.54	15	3.8×10^7
59	本	Q	Y	7.3	0.53	13	3.3×10^7
60	比	Q	Z	* 4.4	0.53	* 7	2.8×10^7
61	比	R	W	* 4.6	0.52	*10 $	4.3×10^7
62	本	R	X	7.5	0.53	19	4.5×10^7
63	本	R	Y	7.3	0.53	17	4.2×10^7
64	比	R	Z	* 4.5	0.52	* 9.5	4.7×10^7

1) 区分欄の「本」は本発明例、「比」は比較例を表す。
2) * 印は本発明で規定する範囲から外れていることと、目標に達していないことを示す。
3) $ 印は各鋼における切削性の基準値であることを示す。

The trial using the ** mark A of the example of a comparison, and the steel of I-N so that clearly from Table 3 and 4, that is C content less than 0.8% of ** mark A steel The used test numbers 1-4, the test numbers [value / (X=1.6x%Si+4.0x%Mn+3.0x%Cr+5.0x%Mo) / X] 25-28 using less than 5.0 ** mark I steel, the test numbers 29-32 using the ** mark J steel with which aluminum content exceeds 0.05%, and Ti content 0.002% The ** mark K steel which exceeds The used test numbers 33-36, the test numbers 37-40 using the ** mark L steel with which P content and S content exceed 0.02% and 0.015%, respectively, the test numbers 41-44 using the ** mark M steel with which N content exceeds 0.009%, and O content 0.0015% For the test numbers 45-48 using the ** mark N steel which exceeds, a rolling fatigue life is 1.0x107. A time is not reached.

[0057] Among the above, since the Cr+Mn concentration in a cementite of test numbers 1, 4, 25, 28, 29, 32, 33, 36, and 41, and 44-46 is less than 5.0%, a tool life has not reached a target value, either.

[0058] Moreover, although it is within the limits as which the chemical composition of steel specifies test numbers 5, 8, 9, 12, 13, 16, 17, 20, 21, 24, 49, 52, 53, 56, 57, 60, 61, and 64 by this invention, since the Cr+Mn concentration in a cementite is less than 5.0%, the tool life has not reached a target value.

[0059] On the other hand, for the test numbers 6, 7, 10, 11, 14, 15, 18, 19, 22, 23, 50, 51, 54, 55, 58, 59, 62, and 63 using ** mark B-I and O-R steel which fulfill the conditions specified by this invention, the tool life has reached the target value and, moreover, a rolling fatigue life is

also 1.0x107 of a target. It has exceeded the time.
[0060] Especially the tool life of 6.0% or more of test numbers 11, 22, 23, 50, 51, 54, 55, 57, 60, 61, and 64 has the Cr+Mn concentration as long as 50% or more in a cementite compared with what carried out spheroidizing on Conditions W, and it excels much more.

[Translation done.]